We claim:

1. An optical apparatus disposed on a substrate, comprising:

first and second ports,
a non-planar port,
and
a plurality of light scattering elements arranged in a plurality of curved rows,
where the first and second ports are in the plane of the substrate,
and the non-planar port is not in the plane of the substrate.

2. The optical apparatus according to claim 1, and further comprising receiving light coupled to the non-planar port,
where the integrated optical apparatus splits orthogonal polarization components of the received light into first and second light outputs directed to the respective first and second ports.

3. The optical apparatus according to claim 1, and further comprising receiving first and second light inputs coupled to the respective first and second ports,
where the integrated optical apparatus couples the received first and second light inputs to respective first and second orthogonal polarization components of a light output directed to the non-planar port.

4. The optical apparatus according to claim 1, and further comprising first and second flared waveguides,

where each of the first and second flared waveguides have a relatively wide end and a relatively narrow end, and

where the wide end of the first and second flared waveguides are coupled to the respective first and second ports.

5. The optical apparatus according to claim 4, and further comprising first and second waveguides coupled to the narrow ends of respective first and second flared waveguides.

6. The optical apparatus according to claim 4, wherein at least one of the first and second flared waveguides is selected from a group comprising: a strip loaded waveguide, a channel waveguide, a rib waveguide and a ridge waveguide.

7. The optical apparatus according to claim 6, wherein the strip loaded waveguide comprises a strip, a slab and a low index transition layer between the strip and the slab.

8. The optical apparatus according to claim 4, wherein at least one of the flared waveguides has at least one curved sidewall.

9. The optical apparatus according to claim 8, wherein at least one of the flared waveguides has at least one substantially hyperbolically curved sidewall.

10. The optical apparatus according to claim 8, wherein at least one of the flared waveguides has two substantially hyperbolically curved sidewalls, where the two curved sidewalls support the guided propagation of circularly cylindrical wavefronts in the flared waveguide.

11. The optical apparatus according to claim 4, wherein
the non-planar port propagates light with substantially planar wavefronts, the first and second flared waveguides propagate light with non-planar wavefronts and
the relatively narrow ends of first and second flared waveguides propagate light with planar wavefronts, and
where the plurality of light scattering elements convert light between planar wavefronts and non-planar wavefronts, and
the relatively narrow ends of the first and second flared waveguides convert light between non-planar wavefronts and planar wavefronts.

12. The optical apparatus according to claim 4, wherein
the non-planar port propagates light with substantially non-planar wavefronts, the first and second flared waveguides propagate light with non-planar wavefronts and
the relatively narrow ends of first and second flared waveguides propagate light with planar wavefronts, and
where the plurality of light scattering elements propagate light with non-planar wavefronts, and
the relatively narrow ends of the first and second flared waveguides convert light between non-planar wavefronts and planar wavefronts.

13. The optical apparatus according to claim 1, wherein the plurality of light scattering elements are positioned at a plurality of points defined by a plurality of intersections of first and second pluralities of curved lines.

14. The optical apparatus according to claim 13, wherein the plurality of light scattering elements are arranged in first and second pluralities of curved rows aligned with the respective first and second pluralities of curved lines.

15. The optical apparatus according to claim 13, wherein each of the first plurality of curved lines is comprised of a respective one of a plurality of substantially concentric homothetic elliptical curves defined by a first pair of foci, and

each of the second plurality of curved lines is comprised of a respective one of a plurality of substantially concentric homothetic elliptical curves defined by a second pair of foci.

16. The optical apparatus according to claim 13, wherein the spacing between the curves of the first plurality of curved lines is substantially uniform, and

the spacing between the curves of the second plurality of curved lines is substantially uniform.

17. The optical apparatus according to claim 13, wherein a minority of the plurality of light scattering elements are not positioned at the plurality of

points defined by the plurality of intersections of first and second pluralities of curved lines.

18. The optical apparatus according to claim 13, wherein a minority of the plurality of light scattering elements are positioned at points in between the plurality of points defined by the plurality of intersections of first and second pluralities of curved lines.

19. The optical apparatus according to claim 1, wherein the plurality of light scattering elements are arranged in first and second pluralities of curved rows,

where at least one of the first plurality of curved rows intersects with at least one of the second plurality of second rows,

each of the plurality of light scattering elements is positioned in both the first and second pluralities of curved rows,

the first plurality of curved rows has a shaped concave side facing the first port, and

the second plurality of curved rows has a shaped concave side facing the second port.

20. The optical apparatus according to claim 19, wherein the spacing between the rows of the first plurality of curved rows is substantially uniform, and

the spacing between the rows of the second plurality of curved rows is substantially uniform.

21. The optical apparatus according to claim 19, wherein the curvatures of the first plurality of curved rows are defined by a first plurality of substantially elliptical paths defined by a first pair of foci, and
the curvatures of the second plurality of curved rows are defined by a second plurality of substantially elliptical paths defined by a second pair of foci.

22. The optical apparatus according to claim 21, wherein the curvatures of the first plurality of curved rows are defined by a first plurality of segments of a respective first plurality of substantially concentric homothetic elliptical curves defined by a first pair of foci, and
the curvatures of the second plurality of curved rows are defined by a second plurality of segments of a respective second plurality of substantially concentric homothetic elliptical curves defined by a second pair of foci.

23. The optical apparatus according to claim 1, wherein at least one of the plurality of curved rows has a substantially elliptically shaped concave side facing the first port, and
at least one other of the plurality of curved rows has a substantially elliptically shaped concave side facing the second port.

24. The optical apparatus according to claim 1, wherein the non-planar port couples an optical signal between an optical element and the integrated optical apparatus.

25. The optical apparatus according to claim 24, wherein the optical element is selected from a group comprising: an optical fiber, a laser, a lens, a light emitting diode, a photodetector, and a grating coupler.

26. The optical apparatus according to claim 25, wherein the optical fiber comprises single mode fiber.

27. The optical apparatus according to claim 25, wherein the optical element is positioned substantially in the near field of the plurality of light scattering elements.

28. The optical apparatus according to claim 25, wherein the optical element is positioned in proximity to the plurality of light scattering elements, and
where the plurality of light scattering elements is substantially within the near field of the optical element.

29. The optical apparatus according to claim 26, wherein the plurality of light scattering elements are positioned substantially within the Rayleigh range of the end of the optical fiber.

30. The optical apparatus according to claim 1, wherein at least one of the plurality of light scattering elements is selected from a group comprising: semiconductor materials, dielectric materials and a structure comprised of at least one semiconductor layer and at least one dielectric layer.

31. The optical apparatus according to claim 1, wherein the shape of at least one of the plurality of light scattering elements is selected from a group comprising: a hole, a cylinder, a pillar, a conic section, a cube, a pyramid, a prism and a polyhedron.

32. The optical apparatus according to claim 1, wherein at least one of the plurality of curved rows is comprised of a set of light scattering elements of various sizes, where a variation in one of the dimensions of the set of light scattering elements is selected from a group comprising: periodic, linear, and as defined by a non-linear mathematical function.

33. The optical apparatus according to claim 1, wherein at least one characteristic of the plurality of light scattering elements varies irregularly in magnitude, where the varying characteristic is selected from the group comprising: width, height, length, spacing, depth and index of refraction.

34. The optical apparatus according to claim 1, wherein the axis of propagation of the second port is substantially orthogonal with respect to the axis of propagation of the first port.

35. The optical apparatus according to claim 1, wherein the axis of propagation of the non-planar port is less than ten degrees with respect to the normal to the surface of the substrate.

36. The optical apparatus according to claim 1, wherein the substrate is selected from the group comprising: silicon, silicon on insulator (SOI), silicon on sapphire (SOS), silicon on nothing (SON) and

a first layer of monocrystalline silicon,
a second layer of dielectric material disposed on the first layer,
a third layer of monocrystalline silicon disposed on the second layer,
a fourth layer of dielectric material disposed on the third layer,
a fifth layer of monocrystalline silicon disposed on the fourth layer.

37. The optical apparatus according to claim 1, and further comprising at least one reflector of at least one layer disposed in at least one of the following configurations with respect to the integrated optical apparatus: on top, on the substrate below, and on top and also on the substrate below.

38. The optical apparatus according to claim 1, and further comprising an anti-reflective coating over the integrated optical apparatus.

39. The optical apparatus according to claim 1, and further comprising a maskwork for fabricating the integrated optical apparatus.

40. An optical apparatus disposed on a substrate, comprising:

a grating coupler with first and second ports and a non-planar port,
where the grating coupler is comprised of:
a waveguide and

a plurality of light scattering elements arranged in a plurality of curved rows in the waveguide,

where the first and second ports are in the plane of the substrate, and

the non-planar port is not in the plane of the substrate.

41. The optical apparatus according to claim 40, and further comprising receiving light coupled to the non-planar port,

where the integrated optical apparatus splits orthogonal polarization components of the received light into first and second light outputs directed to the respective first and second ports.

42. The optical apparatus according to claim 40, and further comprising receiving first and second light inputs coupled to the respective first and second ports,

where the integrated optical apparatus couples the received first and second light inputs to respective first and second orthogonal polarization components of a light output directed to the non-planar port.

43. The optical apparatus according to claim 40, and further comprising first and second flared waveguides,

where each of the first and second flared waveguides have a relatively wide end and a relatively narrow end, and

where the wide end of the first and second flared waveguides are coupled to the respective first and second ports.

44. The optical apparatus according to claim 43, and further comprising first and second waveguides coupled to the narrow ends of respective first and second flared waveguides.

45. The optical apparatus according to claim 43, wherein at least one of the first and second flared waveguides is selected from a group comprising: a strip loaded waveguide, a channel waveguide, a rib waveguide and a ridge waveguide.

46. The optical apparatus according to claim 45, wherein the strip loaded waveguide comprises a strip, a slab and a low index transition layer between the strip and the slab.

47. The optical apparatus according to claim 43, wherein at least one of the flared waveguides has at least one curved sidewall.

48. The optical apparatus according to claim 47, wherein at least one of the flared waveguides has at least one substantially hyperbolically curved sidewall.

49. The optical apparatus according to claim 47, wherein at least one of the flared waveguides has two substantially hyperbolically curved sidewalls, where the two curved sidewalls support the guided propagation of circularly cylindrical wavefronts in the flared waveguide.

50. The optical apparatus according to claim 43, wherein

the non-planar port propagates light with substantially planar wavefronts, the first and second flared waveguides propagate light with non-planar wavefronts and

the relatively narrow ends of first and second flared waveguides propagate light with planar wavefronts, and

where the plurality of light scattering elements convert light between planar wavefronts and non-planar wavefronts, and

the relatively narrow ends of the first and second flared waveguides convert light between non-planar wavefronts and planar wavefronts.

51. The optical apparatus according to claim 43, wherein

the non-planar port propagates light with substantially non-planar wavefronts, the first and second flared waveguides propagate light with non-planar wavefronts and

the relatively narrow ends of first and second flared waveguides propagate light with planar wavefronts, and

where the plurality of light scattering elements propagate light with non-planar wavefronts, and

the relatively narrow ends of the first and second flared waveguides convert light between non-planar wavefronts and planar wavefronts.

52. The optical apparatus according to claim 40, wherein the plurality of light scattering elements are positioned at a plurality of points defined by a plurality of intersections of first and second pluralities of curved lines.

53. The optical apparatus according to claim 52, wherein the plurality of light scattering elements are arranged in first and second pluralities of curved rows aligned with the respective first and second pluralities of curved lines.

54. The optical apparatus according to claim 52, wherein each of the first plurality of curved lines is comprised of a respective one of a plurality of substantially concentric homothetic elliptical curves defined by a first pair of foci, and

each of the second plurality of curved lines is comprised of a respective one of a plurality of substantially concentric homothetic elliptical curves defined by a second pair of foci.

55. The optical apparatus according to claim 52, wherein the spacing between the curves of the first plurality of curved lines is substantially uniform, and

the spacing between the curves of the second plurality of curved lines is substantially uniform.

56. The optical apparatus according to claim 52, wherein a minority of the plurality of light scattering elements are not positioned at the plurality of points defined by the plurality of intersections of first and second pluralities of curved lines.

57. The optical apparatus according to claim 52, wherein a minority of the plurality of light scattering elements are positioned at points in between the

plurality of points defined by the plurality of intersections of first and second pluralities of curved lines.

58. The optical apparatus according to claim 40, wherein the plurality of light scattering elements are arranged in first and second pluralities of curved rows,

where at least one of the first plurality of curved rows intersects with at least one of the second plurality of second rows,

each of the plurality of light scattering elements is positioned in both the first and second pluralities of curved rows,

the first plurality of curved rows has a shaped concave side facing the first port, and

the second plurality of curved rows has a shaped concave side facing the second port.

59. The optical apparatus according to claim 58, wherein the spacing between the rows of the first plurality of curved rows is substantially uniform, and

the spacing between the rows of the second plurality of curved rows is substantially uniform.

60. The optical apparatus according to claim 58, wherein the curvatures of the first plurality of curved rows are defined by a first plurality of substantially elliptical paths defined by a first pair of foci, and

the curvatures of the second plurality of curved rows are defined by a second plurality of substantially elliptical paths defined by a second pair of foci.

61. The optical apparatus according to claim 60, wherein the curvatures of the first plurality of curved rows are defined by a first plurality of segments of a respective first plurality of substantially concentric homothetic elliptical curves defined by a first pair of foci, and
the curvatures of the second plurality of curved rows are defined by a second plurality of segments of a respective second plurality of substantially concentric homothetic elliptical curves defined by a second pair of foci.

62. The optical apparatus according to claim 40, wherein at least one of the plurality of curved rows has a substantially elliptically shaped concave side facing the first port, and
at least one other of the plurality of curved rows has a substantially elliptically shaped concave side facing the second port.

63. The optical apparatus according to claim 40, wherein the non-planar port couples an optical signal between an optical element and the integrated optical apparatus.

64. The optical apparatus according to claim 63, wherein the optical element is selected from a group comprising: an optical fiber, a laser, a lens, a light emitting diode, a photodetector, and a grating coupler.

65. The optical apparatus according to claim 64, wherein the optical fiber comprises single mode fiber.

66. The optical apparatus according to claim 64, wherein the optical element is positioned substantially in the near field of the plurality of light scattering elements.

67. The optical apparatus according to claim 64, wherein the optical element is positioned in proximity to the plurality of light scattering elements, and
where the plurality of light scattering elements is substantially within the near field of the optical element.

68. The optical apparatus according to claim 65, wherein the plurality of light scattering elements are positioned substantially within the Rayleigh range of the end of the optical fiber.

69. The optical apparatus according to claim 40, wherein at least one of the plurality of light scattering elements is selected from a group comprising: semiconductor materials, dielectric materials and a structure comprised of at least one semiconductor layer and at least one dielectric layer.

70. The optical apparatus according to claim 40, wherein the shape of at least one of the plurality of light scattering elements is selected from a group comprising: a hole, a cylinder, a pillar, a conic section, a cube, a pyramid, a prism and a polyhedron.

71. The optical apparatus according to claim 40, wherein at least one of the plurality of curved rows is comprised of a set of light scattering elements

of various sizes, where a variation in one of the dimensions of the set of light scattering elements is selected from a group comprising: periodic, linear, and as defined by a non-linear mathematical function.

72. The optical apparatus according to claim 40, wherein at least one characteristic of the plurality of light scattering elements varies irregularly in magnitude, where the varying characteristic is selected from the group comprising: width, height, length, spacing, depth and index of refraction.

73. The optical apparatus according to claim 40, wherein the axis of propagation of the second port is substantially orthogonal with respect to the axis of propagation of the first port.

74. The optical apparatus according to claim 40, wherein the axis of propagation of the non-planar port is less than ten degrees with respect to the normal to the surface of the substrate.

75. The optical apparatus according to claim 40, wherein the substrate is selected from the group comprising: silicon, silicon on insulator (SOI), silicon on sapphire (SOS), silicon on nothing (SON) and

a first layer of monocrystalline silicon,
a second layer of dielectric material disposed on the first layer,
a third layer of monocrystalline silicon disposed on the second layer,
a fourth layer of dielectric material disposed on the third layer,
a fifth layer of monocrystalline silicon disposed on the fourth layer.

76. The optical apparatus according to claim 40, and further comprising at least one reflector of at least one layer disposed in at least one of the following configurations with respect to the integrated optical apparatus: on top, on the substrate below, and on top and also on the substrate below.

77. The optical apparatus according to claim 40, and further comprising an anti-reflective coating over the integrated optical apparatus.

78. The optical apparatus according to claim 40, and further comprising a maskwork for fabricating the integrated optical apparatus.

79. An optical apparatus disposed on a substrate, comprising:

a waveguide comprising:

a grating coupler and

first and second flared waveguides with respective first and second ports,

where the grating coupler has a non-planar port that is not in the plane of the substrate, and

the first and second ports are in the plane of the substrate,

where each of the first and second flared waveguides has:

a relatively wide end,

a relatively narrow end that comprises the port, and

at least one substantially hyperbolically curved sidewall,

where the relatively wide end of each of the first and second flared waveguides is coupled to the grating coupler.

80. The optical apparatus according to claim 79, and further comprising receiving light coupled to the non-planar port,
where the integrated optical apparatus splits orthogonal polarization components of the received light into first and second light outputs directed to the respective first and second ports.

81. The optical apparatus according to claim 79, and further comprising receiving first and second light inputs coupled to the respective first and second ports,
where the integrated optical apparatus couples the received first and second light inputs to respective first and second orthogonal polarization components of a light output directed to the non-planar port.

82. The optical apparatus according to claim 79, and further comprising first and second waveguides coupled to the narrow ends of respective first and second flared waveguides.

83. The optical apparatus according to claim 79, wherein at least one of the first and second flared waveguides is selected from a group comprising: a strip loaded waveguide, a channel waveguide, a rib waveguide and a ridge waveguide.

84. The optical apparatus according to claim 83, wherein the strip loaded waveguide comprises a strip, a slab and a low index transition layer between the strip and the slab.

85. The optical apparatus according to claim 79, wherein at least one of the flared waveguides has two substantially hyperbolically curved sidewalls, where the two curved sidewalls support the guided propagation of circularly cylindrical wavefronts in the flared waveguide.

86. The optical apparatus according to claim 79, wherein
the non-planar port propagates light with substantially planar wavefronts, the first and second flared waveguides propagate light with non-planar wavefronts and
the relatively narrow ends of first and second flared waveguides propagate light with planar wavefronts, and
where the plurality of light scattering elements convert light between planar wavefronts and non-planar wavefronts, and
the relatively narrow ends of the first and second flared waveguides convert light between non-planar wavefronts and planar wavefronts.

87. The optical apparatus according to claim 79, wherein
the non-planar port propagates light with substantially non-planar wavefronts, the first and second flared waveguides propagate light with non-planar wavefronts and
the relatively narrow ends of first and second flared waveguides propagate light with planar wavefronts, and

where the plurality of light scattering elements propagate light with non-planar wavefronts, and

the relatively narrow ends of the first and second flared waveguides convert light between non-planar wavefronts and planar wavefronts.

88. The optical apparatus according to claim 79, wherein the grating coupler is comprised of a plurality of light scattering elements arranged in a plurality of curved rows.

89. The optical apparatus according to claim 88, wherein the plurality of light scattering elements are positioned at a plurality of points defined by a plurality of intersections of first and second pluralities of curved lines.

90. The optical apparatus according to claim 89, wherein the plurality of light scattering elements are arranged in first and second pluralities of curved rows aligned with the respective first and second pluralities of curved lines.

91. The optical apparatus according to claim 89, wherein each of the first plurality of curved lines is comprised of a respective one of a plurality of substantially concentric homothetic elliptical curves defined by a first pair of foci, and

each of the second plurality of curved lines is comprised of a respective one of a plurality of substantially concentric homothetic elliptical curves defined by a second pair of foci.

92. The optical apparatus according to claim 89, wherein the spacing between the curves of the first plurality of curved lines is substantially uniform, and

the spacing between the curves of the second plurality of curved lines is substantially uniform.

93. The optical apparatus according to claim 89, wherein a minority of the plurality of light scattering elements are not positioned at the plurality of points defined by the plurality of intersections of first and second pluralities of curved lines.

94. The optical apparatus according to claim 89, wherein a minority of the plurality of light scattering elements are positioned at points in between the plurality of points defined by the plurality of intersections of first and second pluralities of curved lines.

95. The optical apparatus according to claim 79, wherein the plurality of light scattering elements are arranged in first and second pluralities of curved rows,

where at least one of the first plurality of curved rows intersects with at least one of the second plurality of second rows,

each of the plurality of light scattering elements is positioned in both the first and second pluralities of curved rows,

the first plurality of curved rows has a shaped concave side facing the first port, and

the second plurality of curved rows has a shaped concave side facing the second port.

96. The optical apparatus according to claim 95, wherein the spacing between the rows of the first plurality of curved rows is substantially uniform, and
the spacing between the rows of the second plurality of curved rows is substantially uniform.

97. The optical apparatus according to claim 95, wherein the curvatures of the first plurality of curved rows are defined by a first plurality of substantially elliptical paths defined by a first pair of foci, and
the curvatures of the second plurality of curved rows are defined by a second plurality of substantially elliptical paths defined by a second pair of foci.

98. The optical apparatus according to claim 97, wherein the curvatures of the first plurality of curved rows are defined by a first plurality of segments of a respective first plurality of substantially concentric homothetic elliptical curves defined by a first pair of foci, and
the curvatures of the second plurality of curved rows are defined by a second plurality of segments of a respective second plurality of substantially concentric homothetic elliptical curves defined by a second pair of foci.

99. The optical apparatus according to claim 79, wherein at least one of the plurality of curved rows has a substantially elliptically shaped concave side facing the first port, and

at least one other of the plurality of curved rows has a substantially elliptically shaped concave side facing the second port.

100. The optical apparatus according to claim 79, wherein the non-planar port couples an optical signal between an optical element and the integrated optical apparatus.

101. The optical apparatus according to claim 100, wherein the optical element is selected from a group comprising: an optical fiber, a laser, a lens, a light emitting diode, a photodetector, and a grating coupler.

102. The optical apparatus according to claim 101, wherein the optical fiber comprises single mode fiber.

103. The optical apparatus according to claim 101, wherein the optical element is positioned substantially in the near field of the plurality of light scattering elements.

104. The optical apparatus according to claim 101, wherein the optical element is positioned in proximity to the plurality of light scattering elements, and
where the plurality of light scattering elements is substantially within the near field of the optical element.

105. The optical apparatus according to claim 102, wherein the plurality of light scattering elements are positioned substantially within the Rayleigh range of the end of the optical fiber.

106. The optical apparatus according to claim 88, wherein at least one of the plurality of light scattering elements is selected from a group comprising: semiconductor materials, dielectric materials and a structure comprised of at least one semiconductor layer and at least one dielectric layer.

107. The optical apparatus according to claim 88, wherein the shape of at least one of the plurality of light scattering elements is selected from a group comprising: a hole, a cylinder, a pillar, a conic section, a cube, a pyramid, a prism and a polyhedron.

108. The optical apparatus according to claim 88, wherein at least one of the plurality of curved rows is comprised of a set of light scattering elements of various sizes, where a variation in one of the dimensions of the set of light scattering elements is selected from a group comprising: periodic, linear, and as defined by a non-linear mathematical function.

109. The optical apparatus according to claim 88, wherein at least one characteristic of the plurality of light scattering elements varies irregularly in magnitude, where the varying characteristic is selected from the group comprising: width, height, length, spacing, depth and index of refraction.

110. The optical apparatus according to claim 79, wherein the axis of propagation of the second port is substantially orthogonal with respect to the axis of propagation of the first port.

111. The optical apparatus according to claim 79, wherein the axis of propagation of the non-planar port is less than ten degrees with respect to the normal to the surface of the substrate.

112. The optical apparatus according to claim 79, wherein the substrate is selected from the group comprising: silicon, silicon on insulator (SOI), silicon on sapphire (SOS), silicon on nothing (SON) and

a first layer of monocrystalline silicon,
a second layer of dielectric material disposed on the first layer,
a third layer of monocrystalline silicon disposed on the second layer,
a fourth layer of dielectric material disposed on the third layer,
a fifth layer of monocrystalline silicon disposed on the fourth layer.

113. The optical apparatus according to claim 79, and further comprising at least one reflector of at least one layer disposed in at least one of the following configurations with respect to the integrated optical apparatus: on top, on the substrate below, and on top and also on the substrate below.

114. The optical apparatus according to claim 79, and further comprising an anti-reflective coating over the integrated optical apparatus.

115. The optical apparatus according to claim 79, and further comprising a maskwork for fabricating the integrated optical apparatus.

116. An optical apparatus, comprising:

an optical fiber and

a waveguide grating coupler disposed on a substrate comprising:

first and second ports,

a non-planar port and

a plurality of light scattering elements arranged in a plurality of curved rows,

where the first and second ports are in the plane of the substrate,

the non-planar port is not in the plane of the substrate,

the waveguide grating coupler propagates light having non-planar wavefronts and couples light having planar wavefronts between the grating coupler and the optical fiber, and

the plurality of light scattering elements convert wavefronts of light between planar wavefronts and non-planar wavefronts.

117. The optical apparatus according to claim 116, and further comprising receiving light coupled to the non-planar port,

where the integrated optical apparatus splits orthogonal polarization components of the received light into first and second light outputs directed to the respective first and second ports.

118. The optical apparatus according to claim 116, and further comprising receiving first and second light inputs coupled to the respective first and second ports,

where the integrated optical apparatus couples the received first and second light inputs to respective first and second orthogonal polarization components of a light output directed to the non-planar port.

119. The optical apparatus according to claim 116, and further comprising first and second flared waveguides,

where each of the first and second flared waveguides have a relatively wide end and a relatively narrow end, and

where the wide end of the first and second flared waveguides are coupled to the respective first and second ports.

120. The optical apparatus according to claim 119, and further comprising first and second waveguides coupled to the narrow ends of respective first and second flared waveguides.

121. The optical apparatus according to claim 119, wherein at least one of the first and second flared waveguides is selected from a group comprising: a strip loaded waveguide, a channel waveguide, a rib waveguide and a ridge waveguide.

122. The optical apparatus according to claim 121, wherein the strip loaded waveguide comprises a strip, a slab and a low index transition layer between the strip and the slab.

123. The optical apparatus according to claim 119, wherein at least one of the flared waveguides has at least one curved sidewall.

124. The optical apparatus according to claim 123, wherein at least one of the flared waveguides has at least one substantially hyperbolically curved sidewall.

125. The optical apparatus according to claim 123, wherein at least one of the flared waveguides has two substantially hyperbolically curved sidewalls, where the two curved sidewalls support the guided propagation of circularly cylindrical wavefronts in the flared waveguide.

126. The optical apparatus according to claim 119, wherein
the non-planar port propagates light with substantially planar wavefronts, the first and second flared waveguides propagate light with non-planar wavefronts and
the relatively narrow ends of first and second flared waveguides propagate light with planar wavefronts, and
where the plurality of light scattering elements convert light between planar wavefronts and non-planar wavefronts, and
the relatively narrow ends of the first and second flared waveguides convert light between non-planar wavefronts and planar wavefronts.

127. The optical apparatus according to claim 119, wherein

the non-planar port propagates light with substantially non-planar wavefronts, the first and second flared waveguides propagate light with non-planar wavefronts and

the relatively narrow ends of first and second flared waveguides propagate light with planar wavefronts, and

where the plurality of light scattering elements propagate light with non-planar wavefronts, and

the relatively narrow ends of the first and second flared waveguides convert light between non-planar wavefronts and planar wavefronts.

128. The optical apparatus according to claim 116, wherein the plurality of light scattering elements are positioned at a plurality of points defined by a plurality of intersections of first and second pluralities of curved lines.

129. The optical apparatus according to claim 128, wherein the plurality of light scattering elements are arranged in first and second pluralities of curved rows aligned with the respective first and second pluralities of curved lines.

130. The optical apparatus according to claim 128, wherein each of the first plurality of curved lines is comprised of a respective one of a plurality of substantially concentric homothetic elliptical curves defined by a first pair of foci, and

each of the second plurality of curved lines is comprised of a respective one of a plurality of substantially concentric homothetic elliptical curves defined by a second pair of foci.

131. The optical apparatus according to claim 128, wherein the spacing between the curves of the first plurality of curved lines is substantially uniform, and

the spacing between the curves of the second plurality of curved lines is substantially uniform.

132. The optical apparatus according to claim 128, wherein a minority of the plurality of light scattering elements are not positioned at the plurality of points defined by the plurality of intersections of first and second pluralities of curved lines.

133. The optical apparatus according to claim 128, wherein a minority of the plurality of light scattering elements are positioned at points in between the plurality of points defined by the plurality of intersections of first and second pluralities of curved lines.

134. The optical apparatus according to claim 116, wherein the plurality of light scattering elements are arranged in first and second pluralities of curved rows,

where at least one of the first plurality of curved rows intersects with at least one of the second plurality of second rows,

each of the plurality of light scattering elements is positioned in both the first and second pluralities of curved rows,

the first plurality of curved rows has a shaped concave side facing the first port, and

the second plurality of curved rows has a shaped concave side facing the second port.

135. The optical apparatus according to claim 134, wherein the spacing between the rows of the first plurality of curved rows is substantially uniform, and
the spacing between the rows of the second plurality of curved rows is substantially uniform.

136. The optical apparatus according to claim 134, wherein the curvatures of the first plurality of curved rows are defined by a first plurality of substantially elliptical paths defined by a first pair of foci, and
the curvatures of the second plurality of curved rows are defined by a second plurality of substantially elliptical paths defined by a second pair of foci.

137. The optical apparatus according to claim 136, wherein the curvatures of the first plurality of curved rows are defined by a first plurality of segments of a respective first plurality of substantially concentric homothetic elliptical curves defined by a first pair of foci, and
the curvatures of the second plurality of curved rows are defined by a second plurality of segments of a respective second plurality of substantially concentric homothetic elliptical curves defined by a second pair of foci.

138. The optical apparatus according to claim 116, wherein at least one of the plurality of curved rows has a substantially elliptically shaped concave side facing the first port, and

at least one other of the plurality of curved rows has a substantially elliptically shaped concave side facing the second port.

139. The optical apparatus according to claim 116, wherein the non-planar port couples an optical signal between an optical element and the integrated optical apparatus.

140. The optical apparatus according to claim 139, wherein the optical element is selected from a group comprising: an optical fiber, a laser, a lens, a light emitting diode, a photodetector, and a grating coupler.

141. The optical apparatus according to claim 140, wherein the optical fiber comprises single mode fiber.

142. The optical apparatus according to claim 140, wherein the optical element is positioned substantially in the near field of the plurality of light scattering elements.

143. The optical apparatus according to claim 140, wherein the optical element is positioned in proximity to the plurality of light scattering elements, and
where the plurality of light scattering elements is substantially within the near field of the optical element.

144. The optical apparatus according to claim 141, wherein the plurality of light scattering elements are positioned substantially within the Rayleigh range of the end of the optical fiber.

145. The optical apparatus according to claim 116, wherein at least one of the plurality of light scattering elements is selected from a group comprising: semiconductor materials, dielectric materials and a structure comprised of at least one semiconductor layer and at least one dielectric layer.

146. The optical apparatus according to claim 116, wherein the shape of at least one of the plurality of light scattering elements is selected from a group comprising: a hole, a cylinder, a pillar, a conic section, a cube, a pyramid, a prism and a polyhedron.

147. The optical apparatus according to claim 116, wherein at least one of the plurality of curved rows is comprised of a set of light scattering elements of various sizes, where a variation in one of the dimensions of the set of light scattering elements is selected from a group comprising: periodic, linear, and as defined by a non-linear mathematical function.

148. The optical apparatus according to claim 116, wherein at least one characteristic of the plurality of light scattering elements varies irregularly in magnitude, where the varying characteristic is selected from the group comprising: width, height, length, spacing, depth and index of refraction.

149. The optical apparatus according to claim 116, wherein the axis of propagation of the second port is substantially orthogonal with respect to the axis of propagation of the first port.

150. The optical apparatus according to claim 116, wherein the axis of propagation of the non-planar port is less than ten degrees with respect to the normal to the surface of the substrate.

151. The optical apparatus according to claim 116, wherein the substrate is selected from the group comprising: silicon, silicon on insulator (SOI), silicon on sapphire (SOS), silicon on nothing (SON) and

a first layer of monocrystalline silicon,
a second layer of dielectric material disposed on the first layer,
a third layer of monocrystalline silicon disposed on the second layer,
a fourth layer of dielectric material disposed on the third layer,
a fifth layer of monocrystalline silicon disposed on the fourth layer.

152. The optical apparatus according to claim 116, and further comprising at least one reflector of at least one layer disposed in at least one of the following configurations with respect to the integrated optical apparatus: on top, on the substrate below, and on top and also on the substrate below.

153. The optical apparatus according to claim 116, and further comprising an anti-reflective coating over the integrated optical apparatus.

154. The optical apparatus according to claim 116, and further comprising a maskwork for fabricating the integrated optical apparatus.